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WATER RESOURCES STUDY MISSISSIPPI RIVER HEADWATERS RESERVOIRS MINNESOTA

Public Health Service
Kansas City, Missouri

December 1963

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WATER RESOURCES STUDY
MISSISSIPPI RIVER HEADWATERS RESERVOIRS
MINNESOTA

Study of Potential Needs and Value of Water Storage for Municipal, Industrial and Quality Control Purposes

LC 70-614773

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VI
Kansas City, Missouri

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WATER RESOURCES STUDY

MISSISSIPPI RIVER HEADWATERS RESERVOIRS

MINNESOTA

Prepared for

DEPARTMENT OF THE ARMY

U. S. Army Engineer District

St. Paul, Minnesota

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VI
Kansas City, Missouri

DECEMBER 1963

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I. INTRODUCTION

Authority

In a letter dated February 5, 1962, the Corps of Engineers, U. S. Army Engineer District, St. Paul, Minnesota, requested the Public Health Service, Region VI, Kansas City, Missouri, to determine the need for and value of reservoir discharges for municipal and industrial water supply and quality control in the Mississippi River above Coon Rapids Dam. The letter reads in part as follows:

"....since our study must consider the advisability of modification of reservoir operation procedures to enhance water supply, both with respect to quality and quantity. Accordingly, it is requested that your agency prepare and submit a report.... .... we are desirous of knowing the degree of control (with respect to water pollution and water quality) and the value of the water supply as afforded by the reservoir discharge made under the present plan of operation. Also desired are your views and comments regarding future requirements, the optimum obtainable water-supply benefits, and your recommendations as to reservoir discharges necessary to provide such benefits...." 19/

This study has been made in accordance with 1) the Water Supply Act of 1958 (Public Law 85-500, Title III) and a Memorandum of Agreement between the Department of the Army and the Department of Health, Education, and Welfare, dated November 4, 1958; and 2) the Federal Water Pollution Control Act (Public Law 84-660) as amended by Public Law 87-88.

Purpose and Scope

The purpose of this study is to determine the present and prospective needs and values of storage in the existing headwaters reservoirs for municipal and industrial (M&I) water supply and water quality control from the Mississippi River Headwaters to the junction of the St. Croix River below the Minneapolis-St. Paul Standard Metropolitan Statistical Area.

The scope of this investigation covers the base year (1965) and the 50-year projections (2015) of the requirements for M&I water supply and water quality control purposes.

Acknowledgments

The cooperation and assistance of many persons and agencies are gratefully acknowledged. Special appreciation is expressed to the following:

1. U. S. Army Engineers, St. Paul District, Corps of Engineers
2. Minnesota Department of Health, Division of Environmental Sanitation
3. Minnesota Department of Conservation, Division of Waters
4. Minnesota Department of Business Development, Division of Industrial Development
5. Minnesota Water Pollution Control Commission
6. Minnesota Water Resources Board
7. Minnesota Office of Iron Range Resources and Rehabilitation
8. U. S. Forest Service, Duluth, Minnesota
9. U. S. Bureau of Mines, Minneapolis, Minnesota

10. Twin Cities Metropolitan Planning Commission
11. St. Paul Planning Commission
12. St. Paul Water Department
13. Minneapolis Water Department
14. Minneapolis-St. Paul Sanitary District
15. St. Cloud Water Department
16. St. Regis Paper Company, Sartell, Minnesota
17. Hennepin Paper Company, Little Falls, Minnesota
18. Blandin Paper Company, Grand Rapids, Minnesota
19. The Herald Review, Grand Rapids
20. Toltz, King, Duvall, Anderson and Associates, Inc. Minneapolis, Minnesota

II. SUMMARY AND CONCLUSIONS

Summary

1) This study is concerned with six Federal reservoirs constructed and operated by the Corps of Engineers. The reservoirs - Winnibigoshish, Leech, Pokegama, Sandy, Pine and Gull - are located in the northern half of Minnesota.

2) The study area includes 26 counties covering the drainage basin of the Mississippi River above Coon Rapids Dam and the Minneapolis-St. Paul Standard Metropolitan Statistical Area (SMSA). The study area is divided into three subareas, each having a predominantly different type of economic activity. The future water needs are based on projected economic development of the subareas.

3) The principal communities of Grand Rapids, Brainerd, Little Falls, St. Cloud, and the Minneapolis-St. Paul SMSA, along with pulp and paper, food and kindred, petroleum, chemical and primary metals industries, constitute the major water users and waste water producers.

4) The need for and value of storage in these reservoirs for municipal and industrial water supplies and quality control is determined. The water requirements and necessary storage releases are given for the years 1965 and 2015.

Conclusions

1) The population of the total study area is expected to increase from a 1960 base of 1.90 million persons to 4.45 million persons in 2015.

2) Based on projected conditions of economic activity the significant 1965 and 2015 water requirements for municipal and industrial uses are shown by trading centers below:

Subareas	Trading Centers	M&I Requirements (MGD) 1965	2015
I	Minneapolis-St. Paul SMSA	240	635
II	St. Cloud	10	25
	Little Falls	4	11
III	Brainerd	6	12
	Grand Rapids	13	27

3) Based on available information and projected conditions water supply storage in the headwaters reservoirs is not needed to meet the 1965 and 2015 municipal and industrial water requirements.

4) Minimum streamflows needed for quality control are shown in Table No. VII-8. Based on available information and projected conditions storage in the headwaters reservoirs is not required for quality control purposes in Subarea II and III. Streamflow regulation required from storage for quality control in Subarea I is shown below:

Year	Draft on Storage Required for Quality Control (Thousand Acre-Feet/Year)
1965	0
1980	91
2000	318
2015	545

5) Maintenance of satisfactory water quality in the Mississippi River will benefit water uses in Subarea I. Recreational opportunities, including fishing, swimming, water skiing, and boating will be increased

for the 1.5 million residents. The aesthetic values of the streams stemming from adequate control of pollution of surface waters and a satisfactory public health environment will be enhanced and the restoration or preservation of property values in areas contiguous to 24 miles of stream will thereby be assured. These benefits may be credited to storage for water quality control only if assurance is given that adequate treatment will be provided.

6) The annual value of storage discounted to 1965 to supply the above streamflow regulation for quality control is $250,000 for a 50-year period.

III. DESCRIPTION OF PROJECT

Purpose

The original purpose for construction of the Mississippi River Headwaters Reservoirs was to benefit navigation on the Mississippi River below the Minneapolis-St. Paul area. Since the construction of a 9-foot canalization, the reservoirs have been operated mainly to serve other interests, including recreation and agriculture.

Location

The headwaters reservoirs system is located in north-central Minnesota. The drainage area of these reservoirs includes parts of 10 counties. Two of the dams - Winnibigoshish and Pokegama - are on the main stem of the Mississippi River and the other four dams are on Leech, Sandy, Pine, and Gull Rivers, respectively. See map in Section X of this report for location of the headwaters reservoirs.

Basin Characteristics

The Mississippi River in the reservoir area follows roughly a circular course, flowing 376 miles to the mouth of Crow Wing River, at which point the Mississippi River is only 75 airline miles from its source. The drainage pattern of the project area consists mainly of large and small lakes and muskegs, connected by rivers and creeks which are dry during the summer months except for storm water runoff.

Water Quality

The chemical characteristics of the Mississippi River below the headwaters reservoirs vary only slightly and the volume of flow has little effect on the chemical quality of the water. 39/ The chemical and physical characteristics of Mississippi River water at Anoka, which is downstream from the Headwaters Reservoirs but above Minneapolis and St. Paul, Minnesota, is present in Table No. III-1. Similar data between the Twin Cities and Hastings, Minnesota are lacking but assumed alike in concentrations.

Table No. III-1

Water Quality of Mississippi River at Anoka, Minnesota 44/

Mississippi River Headwaters Reservoirs Study

	Total Dissolved Solids	Sulfate (SO_4)	Chloride (Cl)	Silica (SiO_2)	Hardness as $CaCO_3$	Color Units	Turbidity as SiO_2
No. of Anal.	32	32	32	32	32	31	9
Mean	200	14	2	11	160	22	6
Maximum	238	18	4	16	205	60	20
Minimum	124	8	0	5	85	3	2

Results in mg/l except color units

All chemical concentrations are less than maximum limits set by the 1962 Public Health Service Drinking Water Standards. The physical characteristics of turbidity and color, at times, exceed the maximum limits of the 1962 Public Health Service Drinking Water Standards.

Pertinent Data

The operating range of the Mississippi River Headwaters Reservoirs is shown in Exhibit No. 2 in the Appendix. The change from the original operating limits to the present operating limits has reduced the reservoirs to about 31 percent of the original flow regulating capacity.

IV. DESCRIPTION OF STUDY AREA

Location and Boundaries

The study area includes the Minneapolis-St. Paul SMSA and the Mississippi drainage area upstream to and including the headwaters reservoirs area.

To facilitate the development of data the study area is confined within county lines. The following 26 counties of Minnesota make up the study area: Aitkin, Anota, Beltrami, Benton, Carver, Cass, Clearwater, Crow Wing, Dakota, Hennepin, Hubbard, Isanti, Itasca, Kandiyoki, McLeod, Meeker, Mille Lacs, Morrison, Ramsey, Scott, Sherburne, Stearns, Todd, Wadena, Washington, and Wright. The study area map in Section X shows the boundaries and location of the study area.

Geography

The headwaters area of the Mississippi is overlain by a mantle of glacial till as much as 300 feet thick. Surface topography ranges from level to very rough hilly sections. Elevations over most of the area are 1,300 to 1,500 feet above mean sea level (msl) but are as high as 1,900 feet near the source of the Mississippi River. The river is crossed by several very extensive terminal moraines deposited by the retreating glaciers, which alternate with wide level areas of till and outwash plains. The Mesabi iron range extends from the northeast into the watershed near Keewatin and terminates several miles southwest of Grand Rapids. The range is crossed by the Mississippi River.

The Mississippi River has many tributaries before it reaches the Minneapolis-St. Paul SMSA. The main tributaries are the Crow Wing, Crow, Rum, and Sauk Rivers.

The Crow Wing Watershed is mostly an upland plain bordered on all sides by morainal hills and ridges. Elevations range from about 1,650 feet in the northwest part of the area to near 1,150 feet at the mouth.

The northern half of the Crow River Watershed consists of low morainic hills and interspersed glacial till plains with elevations ranging from 1,200 to 1,300 feet. The southern half is an undulating clayey till plain with elevations 1,000 to 1,100 feet above msl.

The northern half of the Rum River Watershed is an undulating glacial till plain containing numerous marshes and crossed by several morainal ridges. The southern half consists of hills that rise above a glacial outwash plain. The elevations range from 1,248 feet at the Mille Lacs Lake, the source, to 833 at the mouth.

The Sauk River along with the Mississippi, in the area between the headwaters and the twin cities of Minneapolis-St. Paul, is mostly a rolling glacial till plain at elevations of 950 to 1,100 feet.

The area on both sides of the Mississippi River in Minneapolis-St. Paul SMSA shows the effects of glaciation and accordingly the topography varies considerably from place to place. Hilly glacial moraines are located near the western and eastern boundaries. The central part of the area is largely rolling till plain. In many places along the stream valleys, outcrops of bedrock appear at the surface; whereas in the buried

bedrock valleys the cover of glacial drift is as much as 350 feet thick. Most of the plateau-like uplands are at elevations of 800 to 1,000 feet, separated by steep-walled gorges with alluvial floors at elevations near 700 feet above msl. There are more than 400 lakes and three major rivers - Mississippi, Minnesota, and St. Croix - in the Minneapolis-St. Paul area. The Mississippi and St. Croix Rivers have well-sustained flows during the period of low rainfall. The Minnesota River has less favorable flow characteristics.

Climate

The climate of the study area is characterized by cold winters and fairly short but productive growing seasons with most of the precipitation occurring during the growing season. Climatological data are given for the northern area (location of the headwaters reservoirs) and the southern area (location of the Twin Cities) because of a marked difference.

Table No. IV-1

Climatological Data

Mississippi River Headwaters Reservoirs Study

Area	Temperature (°F) Annual (Mean)	January (Mean)	July (Mean)	Average Killing Frost Date Last	First	Precipitation Annual (Mean)
Southern	45	14	72	May 10	Sept 30	27.5"
Northern	38	4	68	May 25	Sept 20	23.5"

Principal Communities and Industries

The principal communities in the study area are: Bemidji, Grand Rapids, Brainerd, Little Falls, St. Cloud, and the Minneapolis-St. Paul SMSA. These communities are located on the Mississippi River. Exhibit No. 3 lists all municipalities of over 1,000 population.

The industries in the study area with major water requirements and waste water disposal are: The pulp and paper industry, with mills located in or near Grand Rapids, Brainerd, Little Falls, and the Twin Cities; the food and kindred industry, with plants in St. Cloud and the Twin Cities; and the petroleum, chemical, and primary metal industries located in the Twin Cities.

V. ECONOMY

To efficiently develop the water resources for competitive uses and effectively supply the present and projected needs of the study area, the past, present and future economic conditions are investigated. The projected economic development is the basis of the future M&I water requirements and waste loads on which quality control requirements are determined.

Past and Present

General

To obtain a more meaningful economic analysis, the Mississippi River Headwaters Reservoirs study area was divided into three separate subareas. Each subarea can be identified by a predominantly different type of economic activity. The map titled "Economic Subareas" at the end of this section shows the boundaries of the subareas.

The economy of the total Mississippi River Headwaters Reservoirs study area is well diversified. The southeast portion (Subarea I) contains the heavily populated Minneapolis-St. Paul SMSA and the counties which can reasonably be expected to become part of the SMSA before 2015. The subarea depends primarily on the services and manufacturing to support its economy. The central portion (Subarea II) and the northern portion (Subarea III) of the study area depend on the service establishments and agriculture to support their economy. Refer to Table No. V-1 for employment data.

In 1960, Subarea I had a total labor force of about 620,000 persons. Seventy percent of this total (about 435,000) was employed in the

Table No. V-1

The Number and Percentage of the Labor Force by Major Classifications [23/]

Mississippi River Headwaters Reservoirs Study

1950 - 1960

	Sub-Area I				Sub-Area II				Sub-Area III			
	1950		1960		1950		1960		1950		1960	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Farm	17,400	4.0	11,771	2.0	43,165	43.0	30,649	29.0	16,109	29.0	8,654	16.0
Mining	384	-	403	-	398	-	116	-	4,082	7.0	3,787	7.0
Manufacturing	121,416	24.0	153,279	25.0	8,137	8.0	15,272	15.0	4,368	8.0	5,075	10.0
TOTAL BASIC	139,200	28.0	165,453	27.0	51,700	51.0	46,037	44.0	24,559	44.0	17,516	33.0
TOTAL SERVICE	347,038	68.0	433,264	70.0	45,454	46.0	53,279	51.0	26,591	49.0	28,548	57.0
UNEMPLOYED	17,989	4.0	22,751	3.0	2,866	3.0	4,957	5.0	3,759	7.0	5,157	10.0
TOTAL LABOR FORCE	504,227	100.0	621,468	100.0	100,020	100.0	104,273	100.0	54,909	100.0	51,221	100.0

services, while 25 percent (about 153,000) was employed in manufacturing. Three percent was unemployed and the remaining two percent was employed in agriculture.

Subarea II had a total labor force of about 104,000 in 1960. Fifty-one percent was employed in the services. Twenty-nine and 15 percent were employed in agriculture and manufacturing, respectively. Five percent was unemployed.

Subarea III had a total labor force of about 51,000 in 1960 of which 57 percent was employed in the services. Sixteen, ten, and seven percent were employed in agriculture, manufacturing, and mining, respectively. The remaining ten percent of the labor force was unemployed.

Population

The population of the total study area has increased from 974,969 in 1910 to 1,970,322 in 1960. The principal portion of the increase is attributable to Subarea I (Minneapolis-St. Paul SMSA) which increased from about 653,000 in 1910 to over 1.5 million in 1960. Subarea II increased from 221,028 to 291,553 and Subarea III increased from 100,758 to 153,472 during the same period. Refer to Table No. V-2 for population data.

Manufacturing

The total study area is undergoing industrialization when measured by the increases in manufacturing employment. The total study area's manufacturing employment increased from about 134,000 in 1950 to approximately 174,000 in 1960.

Subarea I had the largest growth, increasing from about 121,000 in 1950 to over 153,000 in 1960. In 1960, the three largest categories

Table No. V-2

Population Data

Mississippi River Headwaters Reservoirs Study [20/]

	1910	1920	1930	1940	1950	1960
Sub-area I	653,182	759,516	913,318	1,000,558	1,185,695	1,525,297
Urban	653,182	759,516	913,318	1,000,558	1,185,695	1,525,297
Rural	-	-	-	-	-	-
Sub-area II	221,028	248,115	253,784	271,912	273,317	291,553
Urban	23,401	38,703	46,512	54,399	66,168	79,329
Rural	197,627	209,412	207,272	217,313	207,149	212,224
Sub-area III	100,759	135,865	134,290	162,850	157,048	153,472
Urban	13,625	23,091	29,147	34,890	38,419	40,178
Rural	87,134	112,774	105,143	127,960	118,629	113,294
TOTAL STUDY AREA	974,969	1,143,496	1,301,392	1,435,320	1,616,060	1,970,322
Urban	690,208	821,310	988,977	1,090,047	1,290,281	1,644,804
Rural	284,761	322,186	312,415	345,273	325,778	325,518

employing over 80 percent of the total employment were made up by the fabricating metal (which includes machinery and vehicles), food and kindred products, and printing-publishing categories.

Subarea II had increased from about 8,000 in 1950 to over 15,000 in 1960. Fabricating metal, which includes machinery and vehicles, and the food and kindred products are the largest categories, constituting over 75 percent of the total manufacturing employment.

Subarea III has shown the smallest increase in manufacturing employment, increasing from about 4,000 in 1950 to about 5,000 in 1960; the largest number being employed in the furniture, lumber, and wood products and other nondurables categories. Table No. V-3 shows manufacturing data for the study area.

Agriculture

The importance of agriculture to the economy of the study area has been increasing when measured by the dollar value of all farm products sold from 1949 to 1959. During this period these values increased from $210 million to $260 million (adjusted to the 1954 value of the dollar).

In 1959, Subarea II was the most important contributor producing over 60 percent of these total values. The area is well suited for livestock and dairy farming and the proximity of the Minneapolis-St. Paul SMSA presents a large market for these products. Table No. V-4 shows agricultural data for the study area.

Minerals

Minerals deposits of commercial value extracted from the study area include iron ore, sand and gravel, clay and stone. Dollar values received from mineral extraction have averaged around $120 million annually

Table No. V-3

Manufacturing Employment 23/

Mississippi River Headwaters Reservoirs Study

1950 - 1960

	Sub-Area I		Sub-Area II		Sub-Area III	
	1950	1960	1950	1960	1950	1960
Manufacturing	121,416	153,279	8,137	15,272	4,368	5,075
Furniture, Lumber & Wood Products	5,553	4,716	415	560	2,135	1,980
Primary Metals	2,943	2,751	105	84	36	45
Fab. Metals, Machinery, Vehicles, other Durables	52,530	79,256	2,948	6,941	362	400
Food & Kindred Products	24,297	27,224	2,753	4,094	637	819
Textile & Apparel	9,764	7,201	426	965	260	212
Printing & Publishing	12,602	17,708	808	1,250	381	518
Chemicals & Allied Prod.	4,352	4,546	144	107	29	47
Nondurables	9,375	9,877	538	1,271	528	1,054

Table No. V-4

Agricultural Data [22/]

Mississippi River Headwaters Reservoirs Study

	Sub-area I			Sub-area II			Sub-area III		
	No. Farms	Cropland Harvested (Acres)	Value all Farm Products Sold (Dollars)	No. Farms	Cropland Harvested (Acres)	Value all Farm Products Sold (Dollars)	No. Farms	Cropland Harvested (Acres)	Value all Farm Products Sold (Dollars)
1949	12,606	793,452	60,858,375	28,596	2,444,094	124,173,517	14,380	662,601	25,422,664
1954	10,881	762,606	59,214,539	26,324	2,326,827	121,330,055	11,700	625,009	24,131,509
1959	9,001	734,855	67,511,913	24,278	2,262,654	162,327,454	8,889	512,432	30,593,816

	Total Study Area		
	No. Farms	Cropland Harvested (Acres)	Value all Farm Products Sold (Dollars)
1949	55,582	3,900,147	210,454,556
1954	48,905	3,714,442	204,676,103
1959	42,218	3,509,941	260,433,183

*Adjusted to the 1954 value of the dollar.

20

over the past five years (adjusted to the 1954 value of the dollar). Over 90 percent of these values were obtained from Subarea III where large volumes of iron ore are extracted from Itasca and Crow Wing Counties (Subarea III). Mining employment has remained relatively stable from 1950 to 1960 at about 4,000 employees. Approximately 90 percent of this total was employed in Itasca and Crow Wing Counties. Table No. V-5 depicts dollar values received from mineral extraction.

Table No. V-5

Values of Minerals Extracted [24/]

Mississippi River Headwaters Reservoirs Study

1956 - 1960

(Millions of Dollars)*

	1956	1957	1958	1959	1960	Minerals Extracted in Order of Importance
Subarea I	5.2	5.9	5.8	5.1	5.8	Sand & Gravel, Stone, Clay
Subarea II	3.2	4.3	4.6	4.0	3.4	Sand & Gravel
Subarea III	135.3	148.0	87.5	64.7	105.7	Iron Ore, Manganiferous, Ore, Sand & Gravel, Stone, Clay
TOTAL STUDY AREA	143.7	158.2	97.9	73.8	114.9	

*Adjusted to the 1954 value of the dollar.

Forestry

An abundance of timber resources is available in the study area. Over 7 million acres or about 47 percent of the total gross area is in commercial forest. Subarea III is the principal commercial forest area having about 75 percent of its total area or 6 million acres in commercial forest. Table No. V-6 depicts forest data for the Mississippi River Headwaters Reservoirs study area.

In 1960, employment related directly to timber resources was estimated at about 12,000 or approximately two percent of the total labor force.

Table No. V-6

Forestry Data 32,33/

Mississippi River Headwaters Reservoirs Study

	Gross Area (Million Acres)	Commercial Forest Land (Million Acres)	Percent of Commercial Forest
Subarea I	1.9	.2	11
Subarea II	5.3	.9	17
Subarea III	8.0	6.0	75
TOTAL STUDY AREA	15.2	7.1	47

Future

The presence of the Minneapolis-St. Paul SMSA should have the most important effect on the future growth in the study area. The increased market in Subarea I is expected to have a significant effect on the demand for food, minerals, and forest products and manufacturing throughout the remainder of the study area. The presence of desirable recreational areas throughout the study area will provide recreation for the increased population.

Regional and national increases in demand for manufacturing products will be partially met by industries within the study area. Manufacturing employment for the study area is expected to increase from the 1960 base of 173,000 to 438,000 in 2015. The largest part is expected in Subarea I

with an increase from 153,000 employees in 1960 to 362,000 employees in 2015. Employment in Subarea I is expected to be diversified, with the major portion of the employment in the fabricating metals, machinery, vehicles, other durables, and the food and kindred products categories. Table No. V-7 depicts employment projections for the study area.

Agriculture should continue its high rate of production and increase about 200 percent by 2015; about 80 percent of this increase being produced in Subarea II and utilized in Subarea I (Minneapolis-St. Paul SMSA). Technology should continue to increase and the total labor force should decrease from 50,000 in 1960 to 26,000 in 2015.

Mineral extraction of sand and gravel, clay, and stone should continue. The depletion of the high grade iron ore reserves in the Mesabi Range area has brought about a shift to the extraction of taconite. Taconite is a low grade iron ore, which is ground to a fine product, separated, and pelletized. These pellets have a high iron and low silica content and a preferred structure that increases blast furnace capacity. There is presently a large demand for this product and this demand is expected to increase in the future. 34/ Taconite is usually defined as magnetic or nonmagnetic. The magnetic taconite presently being produced is located east of the study area. Although studies are presently being conducted, no economic methods have been developed to utilize the nonmagnetic taconite located in Subarea III. It was assumed for this preliminary report that the nonmagnetic taconite would not be used during the study period, therefore the large portion of

Table No. V-7

Projected Employment of the Labor Force

Mississippi River Headwaters Reservoirs Study

2015

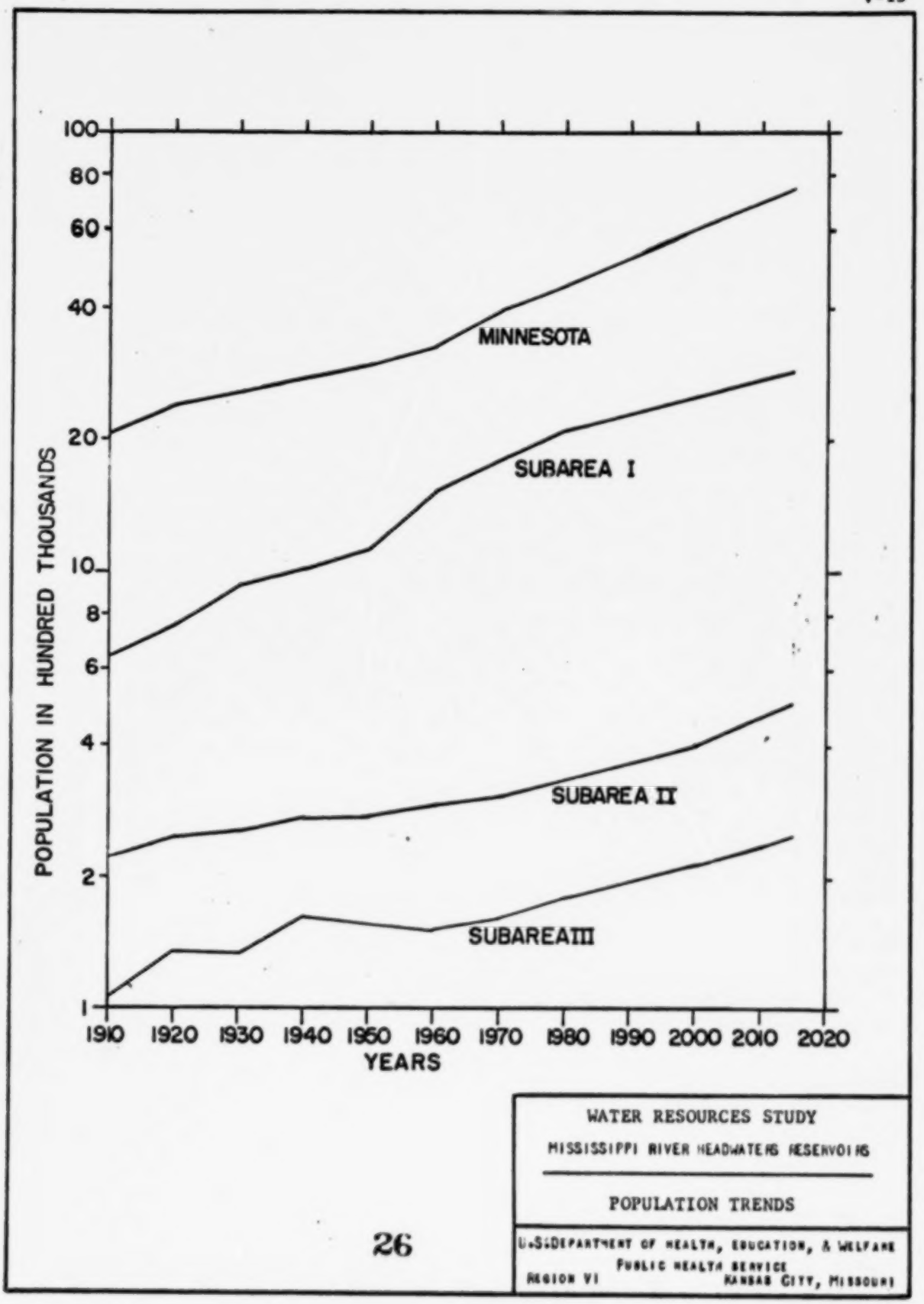
	Subarea I		Subarea II		Subarea III		Total Study Area	
	Number	Percent of Labor Force	Number	Percent of Labor Force	Number	Percent of Labor Force	Number	Percent of Labor Force
Farm	2,400	.2	17,600	9.4	6,000	6.7	26,000	1.4
Mining	300	-	200	.1	4,500	5.1	5,000	.3
Manufacturing	362,100	24.4	59,660	31.9	16,000	18.0	437,760	25.0
Furn., Lbr., & Wood Products	(15,000)	(4.1)	(1,100)	(1.8)	(4,000)	(25.0)	(20,100)	(4.6)
Primary Metal	(7,600)	(2.1)	(1,900)	(3.2)	-	-	(9,500)	(2.2)
Fabr. Metals, Mach., Vehicles and other durables	(171,100)	(47.3)	(23,500)	(39.4)	(2,400)	(15.0)	(197,000)	(45.0)
Food & Kindred Prods.	(76,700)	(21.2)	(15,700)	(26.3)	(3,600)	(22.5)	(96,000)	(21.9)
Textile & Apparel	(19,100)	(5.3)	(3,400)	(5.7)	(1,500)	(9.4)	(24,000)	(5.5)
Prtg. & Publishing	(30,600)	(8.5)	(6,100)	(10.2)	(1,500)	(9.4)	(38,200)	(8.7)
Chemical & Allied Products	(11,400)	(3.0)	(1,900)	(3.2)	(1,000)	(6.3)	(14,300)	(3.3)
Other nondurables	(30,600)	(8.5)	(6,060)	(10.2)	(2,000)	(12.4)	(38,660)	(8.8)
TOTAL BASIC	364,800	24.6	77,460	41.4	26,500	29.8	468,760	26.7
TOTAL SERVICE	1,056,000	71.4	102,000	54.6	59,000	66.2	1,217,000	69.3
UNEMPLOYED	59,200	4.0	7,540	4.0	3,500	4.0	70,240	4.0
TOTAL LABOR FORCE	1,480,000	100.0	187,000	100.0	89,000	100.0	1,756,000	100.0

the mining labor force in Subarea III is expected to continue to work in the magnetic taconite fields and reside in the study area. Subarea I and II are expected to have a small number employed in mining for the extraction of sand and gravel, clay, and stone.

The increased national and regional demand for timber products will be met in part by the study area. Good forestry management practices are presently being undertaken and net growth can be expected to increase. Employment in the categories related to timber resources is expected to have a substantial increase from about 12,000 in 1960 to about 25,000 in 2015. This increase also includes employment in a number of pulp and paper mills located along the Mississippi River in the study area. 35/

The population of the total study area is expected to increase from a 1960 base of 1.90 million to 4.45 million in 2015. The major portion of this increase is expected to be in Subarea I, increasing from about 1.5 million in 1960 to about 3.0 million in 2000 and this rate of increase should continue and reach approximately 3.7 million in 2015. For statistical interpretation Subarea I (Minneapolis-St. Paul SMSA) population should be considered entirely urban by 2015. (This projection corresponds closely with the projection made by the Twin Cities Metropolitan Planning Commission, State of Minnesota, Department of Conservation, and the Senate Select Committee Prints.) 29,1,36/

The remainder of the study area (Subarea II and III) should increase from its 1960 base of 445,000 to about 750,000 in 2015. Of the 2015 total, 200,000 is expected to be rural and 450,000 urban. Figure No. V-1 displays population projections for Subareas I, II, and III. 36/


100
80
60
40
20
10
8
6
4
2
1
POPULATION IN HUNDRED THOUSANDS
MINNESOTA
SUBAREA I
SUBAREA II
SUBAREAIII
1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
YEARS
WATER RESOURCES STUDY
MISSISSIPPI RIVER HEADWATERS RESERVOIRS
POPULATION TRENDS
26
U.S.DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
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KANSAS CITY, MISSOURI

Figure V-1

VI. WATER RESOURCES

Ground Water

Throughout the study area ground water is available in usable quantity and quality from one or more aquifers. (General descriptions of quantity present an abundance of supply. [1,2,5,6] Analyses show the water to be of usable quality for most M&I purposes.[38,44]) Many industries and all the municipalities, with the exception of St. Cloud, Akeley, Howard Lake, Minneapolis, and St. Paul, obtain all of their water supplies from ground sources.

In the northern third of the study area, which includes the headwaters of the Mississippi River, ground water of good quality occurs most abundantly in glacial drifts. Water is also obtained from the ore deposits of the iron formations of the Mesabi and Cuyuna ranges located in the northeastern section of the area. Water in the glacial drift is available in variable quantities depending on the source and distribution of the drift and size and thickness of enclosed sand and gravel deposits or lenses. Inasmuch as the porosity and permeability of the glacial drift is generally high, the total storage and annual changes in storage of ground water in the area are probably large. This is indicated by the character of the glacial drift and is substantiated by the relatively stabilized streamflow during periods of low or deficient precipitation.

The geological conditions are generally favorable for recharge of the glacial drift. The zones of the iron formations are more porous and permeable than the original unaltered rock as a result of leaching

of the silicates, and consequently these leached zones form basin-shaped ground water reservoirs. Large quantities of water are pumped from the ore deposits each year.

Because of the abundance of ground water in relatively shallow drift, wells are not usually drilled into the Precambrian bedrock. However, the upper fissured and fractured zones of Precambrian granite and metamorphic rock, as well as their uppermost weathered zones, may be possible sources of supplies of ground water.

In the central section of the study area, water is still mainly found in the thick deposits of glacial drift. In the eastern part of this section the lenses of the glacial drift are generally thin and discontinuous and exhibit abrupt changes in storage and permeability characteristics in short distances. Below the glacial drift in a few areas the cretaceous formations may furnish small supplies of water. The Precambrian crystalline rocks may also yield small quantities of ground water from fractures and joints.

In the south section of the study area the glacial drift has, in most parts, an abundant supply of water. In the Twin Cities' metropolitan area, ground water is available in usable quantities from aquifers in glacial drift, Paleozoic sandstone, limestone, dolomite and Precambrian sandstone. Paleozoic aquifers of sandstone, limstone, and dolomite form the well-known Twin Cities' artesian basin. See Exhibit No. 5.

The St. Peter sandstone is generally the highest bedrock aquifer in the stratigraphical section. It furnishes adequate water for many users

who do not have large requirements. The Jordan sandstone has generally been regarded as the most prolific aquifer in the artesian basin. Also the overlying Shakopee-Oneota dolomites above the Jordan sandstone have large amounts of water. Below the Jordan sandstone, ground water is available from the Franconia and Desbach sandstone and from the Precambrian Hinchley sandstone.

Of the estimated 380 mgd total ground water recharge in the Twin Cities' SMSA, it is probable that an ultimate supply of about 250 mgd could be developed without serious lowering of the piezometric surface. 1/ Of the 250 mgd, development of a sustained supply of more than 200 mgd in the near future cannot be confidently predicted in view of the legal and political obstacles that must be overcome. 1/

Surface Water

The Mississippi River has its source in Lake Itasca, at an elevation of 1,463 feet above sea level. Much of the headwaters area is heavily forested. Over 75 percent of the area is forest-covered and uncultivated land. Many lakes, swamps and open-bogland provide natural water storage, which is conducive to rather well-sustained streamflow. The six control reservoirs of the Mississippi River headwaters can appreciably effect the flow in this river.

From Lake Itasca the river follows an almost circular course for 370 miles to Brainerd, Minnesota. From Brainerd it flows south and southeast for 150 miles to the Twin Cities where it is joined by its largest

tributary, the Minnesota River. A short distance downstream it is joined by another large tributary, the St. Croix River. Above the Twin Cities, the Mississippi River drains a watershed of about 19,400 square miles and the average slope of the river is about 2.5 feet per mile. The Mississippi, St. Croix, and Minnesota Rivers converge in the Metropolitan area of Minneapolis and St. Paul. Their combined watershed area is nearly 45,000 square miles. Annual runoff varies from about one inch in the headwaters of the Minnesota to about 10 inches in parts of the St. Croix valley. 1/

The St. Croix River, which forms the boundary between Minnesota and Wisconsin, drains an area of about 7,650 square miles. The headwaters of the St. Croix is characterized by many flat, poorly drained, open bogs and numerous lakes. The large amount of natural storage provided on the surface and in the ground produces well-sustained flows in the stream.

The Minnesota River rises on the border between Minnestoa and South Dakota and has a total watershed area of about 16,900 square miles. Almost the entire watershed is cultivated. Much of the natural storage once provided by sloughs and shallow lakes has been destroyed by drainage and the stream does not have a well-sustained flow. The river has its source in Big Stone Lake from which it flows southeast approximately 224 miles to Mankato, Minnesota, where it turns and flows northeast about 106 miles to its junction with the Mississippi River in the Minneapolis-St. Paul SMSA.

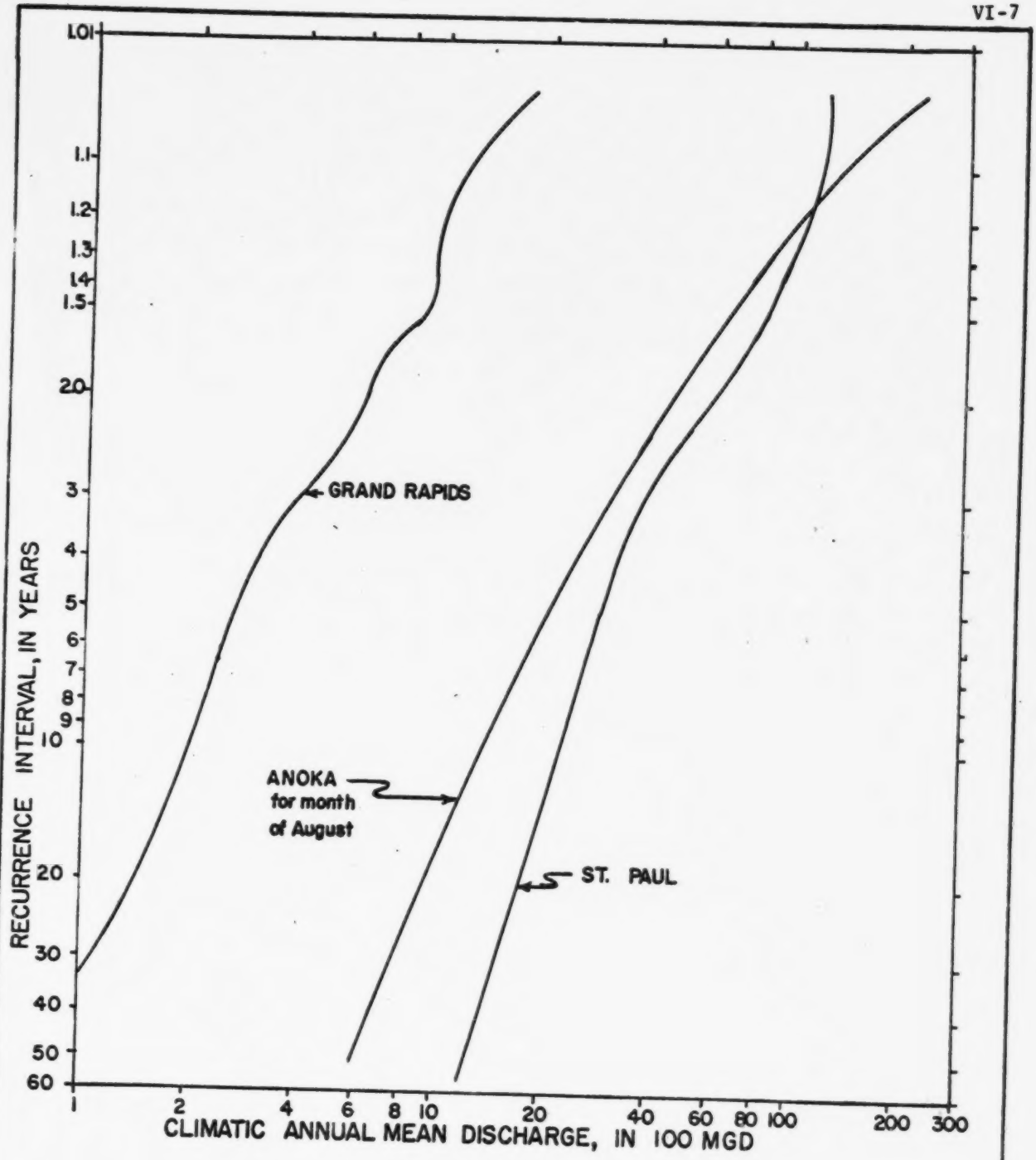
Histroical streamflows in the Mississippi, St. Croix and Minnesota Rivers shown in Exhibit No. 6 include the maximum, minimum, and average flows for comparison purposes.

The Grand Rapids gaging station downstream from Pokegama Dam presents the flow at Grand Rapids. The gaging station on the Mississippi River near Anoka is located below Coon Rapids Dam and above the present water supply intakes of the cities of Minneapolis and St. Paul. The St. Paul gaging station is located downstream from the Minneapolis-St. Paul sanitary district outfall and records the combined flow of the Mississippi and Minnesota Rivers. The gaging station at Prescott, Wisconsin, records the combined flow of the Mississippi, Minnesota, and St. Croix Rivers.

The quantity of water versus recurrence interval is shown in Figures No. VI-1 and VI-2. The curves on these figures were developed on the 1930 through 1960 climatological year, with the exception of the flow-duration curve labeled Anoka which was based on the 1930 through 1960 August data. The curves in Figure No. VI-1 were developed from synthesized records 46/ of the discharges which would have occurred without the reservoirs in place. Figure No. VI-2 curves were developed from actual records 45,55/ of the flow with the reservoirs in place.

Extensive analyses show the water to have a low mineral solids content usable for M&I supply purposes. 38,42,44,47,49/ The chemical characteristics of the water of the Mississippi, Minnesota, and St. Croix Rivers vary but all meet the Public Health Service Drinking Water Standards. The chemical characteristics of the Mississippi River vary only slightly

in the study area and the volume of flow apparently has little effect on this variation. 39/ Sulfates, chlorides and total dissolved solids concentrations in the river water are well below the maximum limits of the Public Health Service Drinking Water Standards. Color and turbidity of the water in the headwaters reservoirs and the Mississippi and St. Croix Rivers sometimes exceed the limits of the Public Health Service Drinking Water Standards but satisfactory levels are easily attained by treatment.



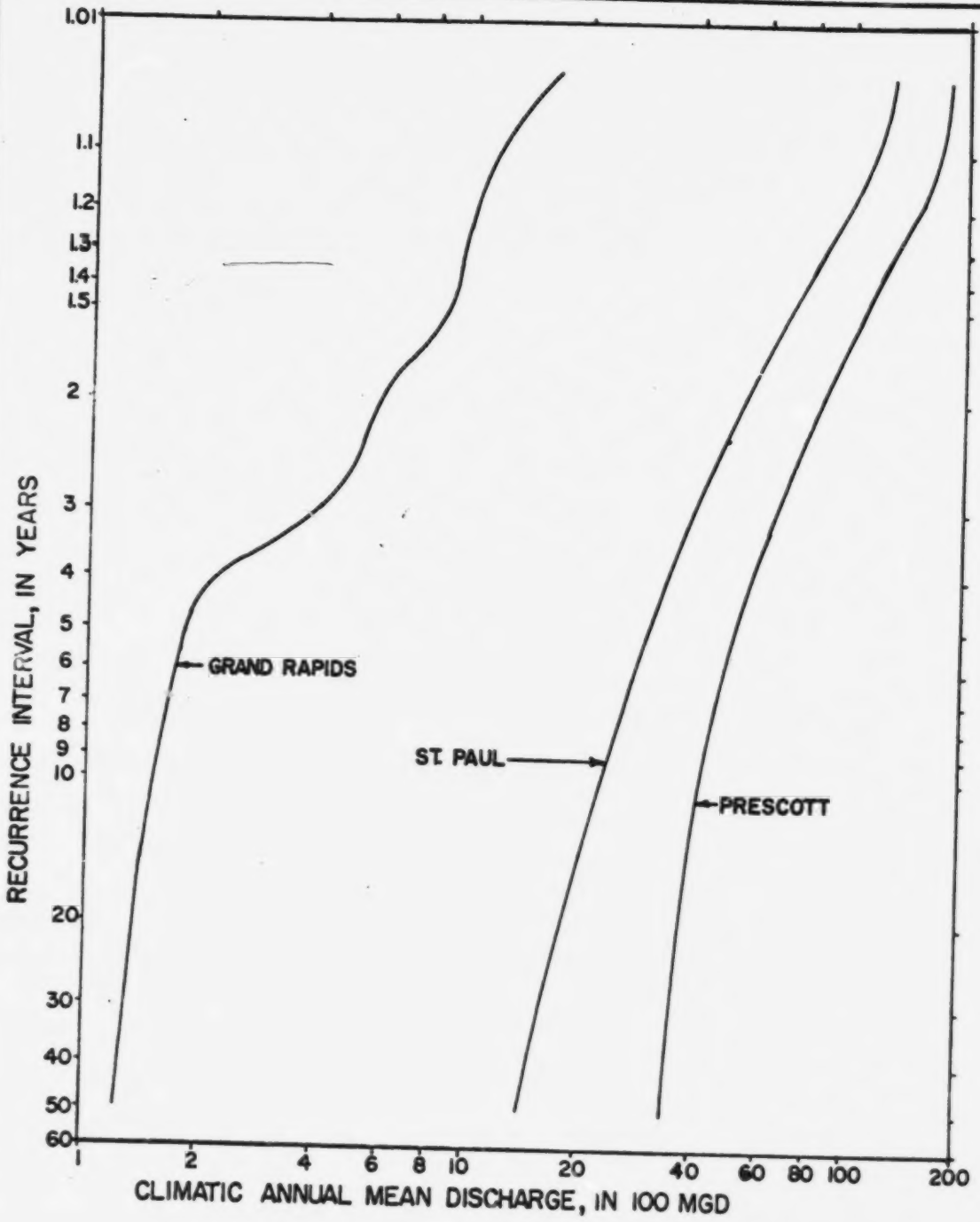
WATER RESOURCES STUDY

MISSISSIPPI RIVER HEADWATERS RESERVOIRS

LOW-FLOW FREQUENCIES CURVES
WITHOUT RESERVOIRS IN PLACE

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VI — KANSAS CITY, MISSOURI

Figure VI-1



W/

WATER RESOURCES STUDY

MISSISSIPPI RIVER HEADWATERS RESERVOIRS

LOW-FLOW FREQUENCIES CURVES
WITH RESERVOIRS IN PLACE

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VI
KANSAS CITY, MISSOURI

Figure VI-2

VII. WATER REQUIREMENTS

Historic Municipal and Industrial

Most municipalities in the study area use ground water. The exceptions are: St. Cloud using the Mississippi River; Akeley using the Eleventh Crow Wing Lake; Howard Lake obtaining part of its water from Howard Lake; and Minneapolis and St. Paul using both the Mississippi River and ground water. Data on municipal water systems, for municipalities with over 1,000 population in the study area, are shown in Exhibit No. 3. The largest users of municipal and industrial water in the study area are in the metropolitan area of Minneapolis-St. Paul. Both ground and surface water are used in the metropolitan area. Present water use is shown in Table No. VII-1.

Table No. VII-1

Present Water Use [1/]

Minneapolis-St. Paul Metropolitan Area

Mississippi River Headwaters Reservoir Study

Items	Ground Water	Surface Water	Total
	(Million Gallons/Day)		
Industrial and Commercial	87.8	38.2	126.0
Domestic and Community	19.8	58.6	78.4
Private Domestic	17.0	-	17.0
Miscellaneous	11.6	-	11.6
	136.2	96.8	233.0

The items in Table No. VII-1 are defined as follows: Commercial water use is that which is used by stores, office buildings, theaters, hotels, and restaurants for air conditioning, cleaning, drinking, and

sanitation. Industrial water uses include the cleaning and processing of food and food products, or the cleaning, cooling, processing or transporting all the varied products of industry and for ther operations in industrial plants. Domestic and community use includes domestic supplies, fire protection, street cleaning, and losses in community or oublic water systems. The private domestic use includes water for both suburban and rural homes provided by privately owned wells. The miscellaneous uses include the pumpage to maintain certain lakes at more desirable stages, watering golf courses, irrigation and stock watering.

In the Minneapolis-St. Paul SMSA there are 46 separate municipal water systems. 1/ Minneapolis and St. Paul supply most of the water requirements in the SMSA and both take water from the Mississippi River. Table No. VII-2 presents the 1950 through 1958 water pumpage of Minneapolis and St. Paul and the relative importance of their water sources.

The industries in the study area above the Minneapolis-St. Paul SMSA use both surface and ground water. Large quantities of water are pumped each year from the iron formations of the Mesabi and Cuyuna ranges to facilitate mining operations. Hydroelectric power is produced at many dams in the study area. Thermoelectric plants use surface water extensively for cooling purposes. The pulp and paper and food and kindred industries in the area use large quantities of water in their operations. Present amounts of water used by these industries in the area above Minneapolis-St. Paul are estimated from information

Table No. VII-2

Minneapolis and St. Paul's Water Sources [43/]
(Million Gallons Per Day)

Mississippi River Headwaters Reservoirs Study

	MINNEAPOLIS		ST. PAUL				
Date	Pumpage From River	Water Pumped From Wells	Pumpage From River	Pumpage From Centerville Lakes	Obtained From Gravity Supply (Vadnais Chain)	Taken From Lake Storage	Total Delivery To Plant
1950	54.8	19.1	31.6	1.6	1.2	0.0	33.6
1951	51.1	18.0	18.5	1.4	0.0	11.6	31.5
1952	53.6	18.5	25.9	2.2	0.0	6.0	34.1
1953	55.5	16.6	30.0	2.3	1.0	3.8	37.1
1954	53.3	18.4	24.6	8.8	0.3	3.0	36.7
1955	59.0	19.9	32.9	8.6	0.6	0.0	40.5
1956	53.5	18.8	31.2	5.2	0.2	2.3	38.9
1957	53.2	20.7	26.4	10.9	0.2	0.4	37.9
1958	56.1	21.1	34.4	9.7	0.5	0.0	40.0

obtained during field investigations and are shown in Table No. VII-3.

Table No. VII-3

Present Industrial Water Requirements

Mississippi River Headwaters Reservoirs Study

Area	Industry	Water Requirements (MGD)
St. Cloud	Food & Kindred	1
	Pulp & Paper	6
Little Falls	Pulp & Paper	3
Brainerd	Pulp & Paper	4
Grand Rapids	Pulp & Paper	12

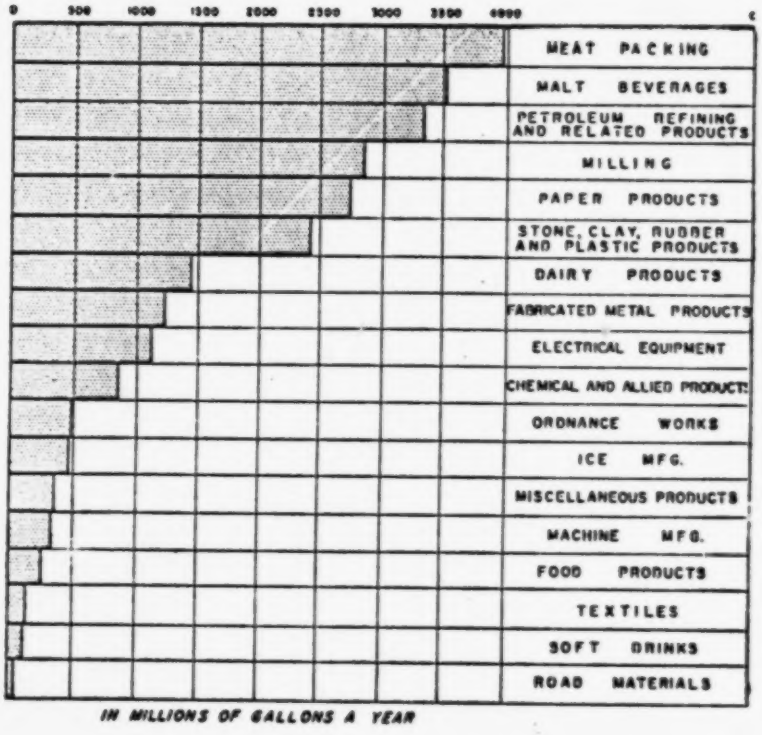
The present industrial water use in the Minneapolis-St. Paul SMSA is presented in conjunction with commercial water use in Table No. VII-1. About 70 percent of this industrial and commercial water use is from ground water. The magnitude of present industrial ground water use by type of industry is shown in Figure VII-1.

The significantly large 1965 M&I water requirements are located by trading centers in Table VII-4. These requirements are rounded estimates from the latest available data [1,49] and field investigations.

Table No. VII-4

Mississippi River Headwaters Reservoirs Study

Trading Center		1965 M&I Requirements
Subarea I	Minneapolis-St. Paul	240 MGD
Subarea II	St. Cloud	10 MGD
	Little Falls	4 MGD
Subarea III	Brainerd	6 MGD
	Grand Rapids	13 MGD



ANNUAL INDUSTRIAL USE OF GROUND WATER IN THE METROPOLITAN AREA 1/

WATER RESOURCES STUDY

MISSISSIPPI RIVER HEADWATERS RESERVOIRS

INDUSTRIAL GROUND WATER USE IN METROPOLITAN AREA

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VI KANSAS CITY, MISSOURI

Figure VII-1

Projected Municipal and Industrial Water Needs

Municipal water requirements include residential, public, commercial and those industrial uses which can reasonably be reflected as a function of municipal population - gallons per capita day (gpcd). Expectations are that the per capita municipal water requirements will increase in the future due to production of more goods and services to satisfy increased consumer demands resulting from a rise in real income.

Water use data on various municipalities in the study area were collected and analyzed to develop Table No. VII-5.

Table No. VII-5

Municipal Water Demand Per Capita

Mississippi River Headwaters Reservoirs Study

Subarea	Year 1965 (gpcd)	Year 2015 (gpcd)
I	100	125
II	75	100
III	75	100

Per capita water use in 1958 for 37 municipalities in Subarea I averaged 104 gpcd with a range of 22 to 178 gpcd. 1/ A 1962 report 39/ gave the community average of 100 gpcd for Minneapolis, 111 gpcd for St. Paul, and 65 to 70 gpcd for adjacent municipalities in Subarea I. In Subarea II an average of 78 gpcd was recorded 39/ for St. Cloud. In Subarea III municipal ground water use ranged from 20 to 130 gpcd. 48,49/ Municipal water use in Subarea II and III were similar. The Senate Select Committee Print 58/ projected per capita water use from municipal systems in Minnesota at 111 gpcd and 113 gpcd in the years 1980 and 2000 respectively. Industrial water requirements are defined as those

requirements that can significantly effect the total water demands in an area. For the purpose of this study those industrial demands considered will be for the 1) pulp and paper, 2) chemical, 3) petroleum refining, 4) primary metals, and 5) food and kindred products industries.

Projections of industrial water requirements can be based on either of two factors: 1) Water use per unit of product, or 2) water use per employee. The water use per employee was selected for this study to utilize the employment projection in the economy section.

Data on industrial water use were obtained from two different sources: 1) Census of Manufactures, Industrial Water Use, 1958; 2) and direct field studies. Other sources [59,60/] of data from consulting firms were analyzed. The field studies data and the 1958 Census of Manufactures data (upper Mississippi region) were similar and selected for this study. Present and projected industrial water requirements are shown in Table No. VII-6.

Table No. VII-6

Industrial Water Demand Per Employee

Mississippi River Headwaters Reservoirs Study

Industry	SIC 2-digit Category	Gallons Per Employee Per Day
Food & Kindred	20	600
Pulp & Paper	26	8,000 - 26,000*
Chemicals	28	1,500
Petroleum	29	400
Primary Metals	33	3,500

*Dependent on type of operation

Projected 2015 water requirements for trading centers with significant M&I water demands are shown in Table No. VII-7. The M&I water requirements shown were computed from the water demand figures in Table No. VII-4 and Table No. VII-5 and projected municipal population and industrial employment.

Table No. VII-7

Municipal and Industrial Water Requirements

Mississippi River Headwaters Reservoirs Study

Subarea	Trading Center	2015 Municipal (MGD)	Industrial (MGD)	Total (MGD)
I	Minneapolis-St. Paul	463	172 (Food & Kindred 46) (Pulp & Paper 80) (Chemicals 17) (Petroleum 2) (Primary Metals 27)	635
II	St. Cloud	12	13 (Food & Kindred 2) (Pulp 11)	25
	Little Falls	5	6 (Pulp 6)	11
III	Brainerd	4	8 (Paper Goods 8)	12
	Grand Rapids	6	21 (Pulp 21)	27

Water Quality Control

Under provisions of the Federal Water Pollution Act, Public Law 84-660 as amended by Public Law 87-88, in the survey or planning of a reservoir by any Federal agency, consideration must be given to the inclusion of storage for regulation of streamflow for the purpose of

water quality control. The crediting of benefits is based on assurance that local agencies either now provide or will provide adequate treatment. In this report water quality control benefits are based on a 90 percent reduction of the biochemical oxygen demand (BOD) of the waste as adequate treatment. The BOD of waste is the quantity of dissolved oxygen in mg/l required during stabilization of the decomposable organic matter by aerobic biochemical action.

Discharge of wastes, even when treated to the maximum economically feasible and practical limit, will cause an unsatisfactory quality condition in receiving waters whose waste assimilation capacity is exceeded. This condition usually occurs during periods of low flows and may be avoided by the addition of water to maintain flows at higher levels. It is essential that recognition be given to the need for flows which must prevail in receiving streams if the quality of their waters are to be maintained at acceptable levels.

The quality objectives are acceptable concentrations of total dissolved solids (TDS), Sulfates (SO_4), chlorides (Cl), and dissolved oxygen (DO). The limits for TDS, SO_4 and Cl are those stated in the 1962 Public Health Service Drinking Water Standards of not greater than 500, 250, and 250 mg/l respectively. The limit for the DO content of water in the stream is not less than 4.0 mg/l. The concentrations of TDS, SO_4 and Cl, as shown in Table No. III-1, are well below the recommended maximum limits and based on projected economic activity, are not expected to exceed these limits. The critical quality objective on which flow requirements are based is the DO concentration.

The DO objective limit is designed to provide an environment suitable for the propagation of fish, prevention of nuisance conditions, and enhance the aesthetic values of the stream and adjacent areas.

The location, watercourse, population served, waste treatment provided and discharge flow of present source of all municipal pollution of significance in the study area are given in Exhibit No. 4. The locations of the larger waste loads presently discharging to the Mississippi River are listed in Table No. VII-4. Waste discharges from Subarea I have the largest total BOD in the study area (see Exhibit No. 1). A survey by the Minneapolis-St. Paul Sanitary District (MSSD) on the Mississippi River in Subarea I disclosed 0.0 mg/l DO during the summer of 1961 on 10 different days. 61/ Average DO and BOD data for winter and summer are given in Table No. VII-8.

Table No. VII-8

Present Mississippi River Water Quality in Subarea 1 61/

Mississippi River Headwaters Reservoirs Study

River Mile*	General Location	1961 Average Data (mg/l) Jan. Feb. March DO	5-day BOD	July Aug. Sept. DO	5-day BOD
0.4	Minneapolis Barge Terminal	11.95	1.55	7.60	3.00
26.5	10 miles below MSSD plant	7.85	13.05	0.40	7.60
37.8	Above Hastings Dam	4.75	7.50	5.80	6.10
39.1	Below Hastings Dam	6.00	6.75	6.15	6.10
-	St. Croix River	12.40	1.40	8.00	2.10

*Channel miles from head of navigation.

The MSSD presently provides primary treatment and is planning the addition of secondary treatment.

The significant discharges of waste in the future are expected to occur at the trading centers with large water use as shown in Table No. VII-7.

Examination of the 1965 and 2015 water requirements and the historic streamflows in Subareas II and III indicates that if water releases for quality control are not necessary on the Mississippi River below Grand Rapids none would be required below Brainerd, Little Falls, and St. Cloud. Therefore calculated flow regulation requirements for water quality control are summarized at Grand Rapids and Subarea I in Table No. VII-9.

Table No. VII-9

Minimum Streamflows for Quality Control

(Flow in MGD)

Mississippi River Headwaters Reservoirs Study

Location / Seasons	Years 1965	1980	2000	2015
Grand Rapids				
Summer	17	-	-	38
Spring & Fall	6	-	-	13
Winter	4			9
Subarea I (Minneapolis-St. Paul)				
Summer	800	2,204	3,087	3,718
Spring & Fall	200	608	772	1,001
Winter	100	304	331	429

Table No. VII-9 does not show releases required. Part or all, in some cases, of these requirements are met by natural runoff.

Water requirements for quality control were calculated by estimating the characteristics and quantities of municipal and industrial wastes and the locations at which they would be discharged to the stream. For

additional details of methodology used to develop Table No. VII-9 see Exhibit No. 1 in the Appendix.

In the event that the flows in the Mississippi River at St. Paul are less than the water requirements for quality control shown in Table No. VII-9, the DO of the water would be less than 4.0 mg/l. As dissolved oxygen concentration declines from saturation, the quality of the aquatic environment and desired suitability for continuing satisfactory growth of all parts of the aquatic life-cycle grows less. While there is no sudden and spectacular die-off when the dissolved oxygen concentration falls to 4.00 mg/l, this value is generally accepted as representing a borderline condition. With more dissolved oxygen, conditions improve markedly and, with less, undesirable results become more apparent, culminating with widespread fish kill when the dissolved oxygen deficiency is complete, i.e. when the DO concentration is zero. Zero DO concentrations would not only result in loss of fish life but also create nuisance conditions seriously damaging the aesthetic and recreational value of the stream and adjacent property.

VIII. WATER SUPPLY AND WATER QUALITY CONTROL PLAN

General

In accordance with the letter of request quoted in part in Section I to determine the value as afforded by the reservoir discharges made under the present plan of operation, the present required storage releases for M&I and quality control purposes are the difference between the present water requirements and the natural streamflows taken from simulated data developed by the Corps of Engineers without the six reservoirs in place. The future required storage releases for M&I and quality control purposes are the difference between the future water requirements and the streamflows with the six headwaters reservoirs in place. The present is defined as 1965 for these purposes.

Municipal and Industrial Water Supply

The 1965 and 2015 M&I water requirements in Subareas I and II, with the exception of St. Cloud, are expected to be adequately filled by abundant ground water sources. The 1965 and 2015 M&I water requirements at St. Cloud are less than the minimum historical flow in this reach of the Mississippi River. (See Exhibit No. 6)

The M&I water requirements and the expected sources for Subares I are shown in Table No. VIII-1.

Table No. VIII-1

M&I Water Requirements and Sources
Subarea I

Mississippi River Headwaters Reservoirs Study

Year	Requirements M&I (MGD)	Sources MGD			
		Ground Water	Lake System	Mississippi River Annual	Mississippi River August
1965	240	136	5	99	133
1980	337	200	10	127	171
2000	491	250	10	231	311
2015	635	250	10	375	505

The critical month is August during which maximum requirements and minimum streamflows usually occur. A 98 percent protection level or a recurrence interval of 50 years is recommended for M&I water supply. Anoka's flow-duration curve, Figure No. VI-1, of August conditions without the six headwaters reservoirs in place, shows a streamflow of 600 mgd at the 50-year recurrence interval. A streamflow of 600 mgd meets both the 1965 and 2015 M&I August requirement expected to be withdrawn from the Mississippi River. Since the smaller streamflow without the six headwaters reservoirs in place satisfies the 2015 M&I requirements, a flow-duration curve at Anoka, with reservoirs in place is not used or presented. The present combined ground and surface water sources in Subarea I are sufficient to supply the 1965 and 2015 municipal and industrial water requirements.

Water Quality Control

A 90 percent protection level or a recurrence interval of 10 years is recommended for flow-regulation requirements for quality control. The climatic annual mean discharges, taken from Figure VI-1 and Figure No. VI-2 are given at three protection levels in Table No. VIII-2.

Table No. VIII-2

Climatic Annual Mean Discharges
(MGD)

Mississippi River Headwaters Reservoirs Study

Location of Gaging Station	Without Reservoirs Protection Level %			With Reservoirs Protection Level %		
	90	70	50	90	70	50
Grand Rapids	190	350	590	150	330	570
St. Paul	2,200	3,400	5,800	3,350	3,600	5,400
Prescott	-	-	-	4,100	6,100	9,000

Monthly mean discharges are proportioned according to the median monthly mean flows.

Based on projected conditions flow regulation is not needed at the 90 percent protection level to meet the 1965 and 2015 quality control requirements at Grand Rapids. Since flow regulation for quality control is not necessary for the critical Grand Rapids' condition, flow regulation to meet the 1965 and 2015 quality control requirements in Subareas II and III are not necessary on the Mississippi River.

In Subarea I natural streamflows without the headwaters reservoirs in place meet the present (1965) quality control requirements at the 90 percent protection level.

The projected 1980, 2000, and 2015 quality control requirements exceed the streamflows with the headwaters reservoirs in place and reservoir storage for flow regulation is necessary. Considering quality control needs and streamflows with the reservoirs in place, Table No. VIII-3 lists the annual draft on storage needed from the headwaters reservoirs to maintain the quality objectives in the Mississippi River in Subarea I.

Table No. VIII-3

Summary of Net Regulation Requirements
in Thousand Acre-Feet Per Year in Subarea I

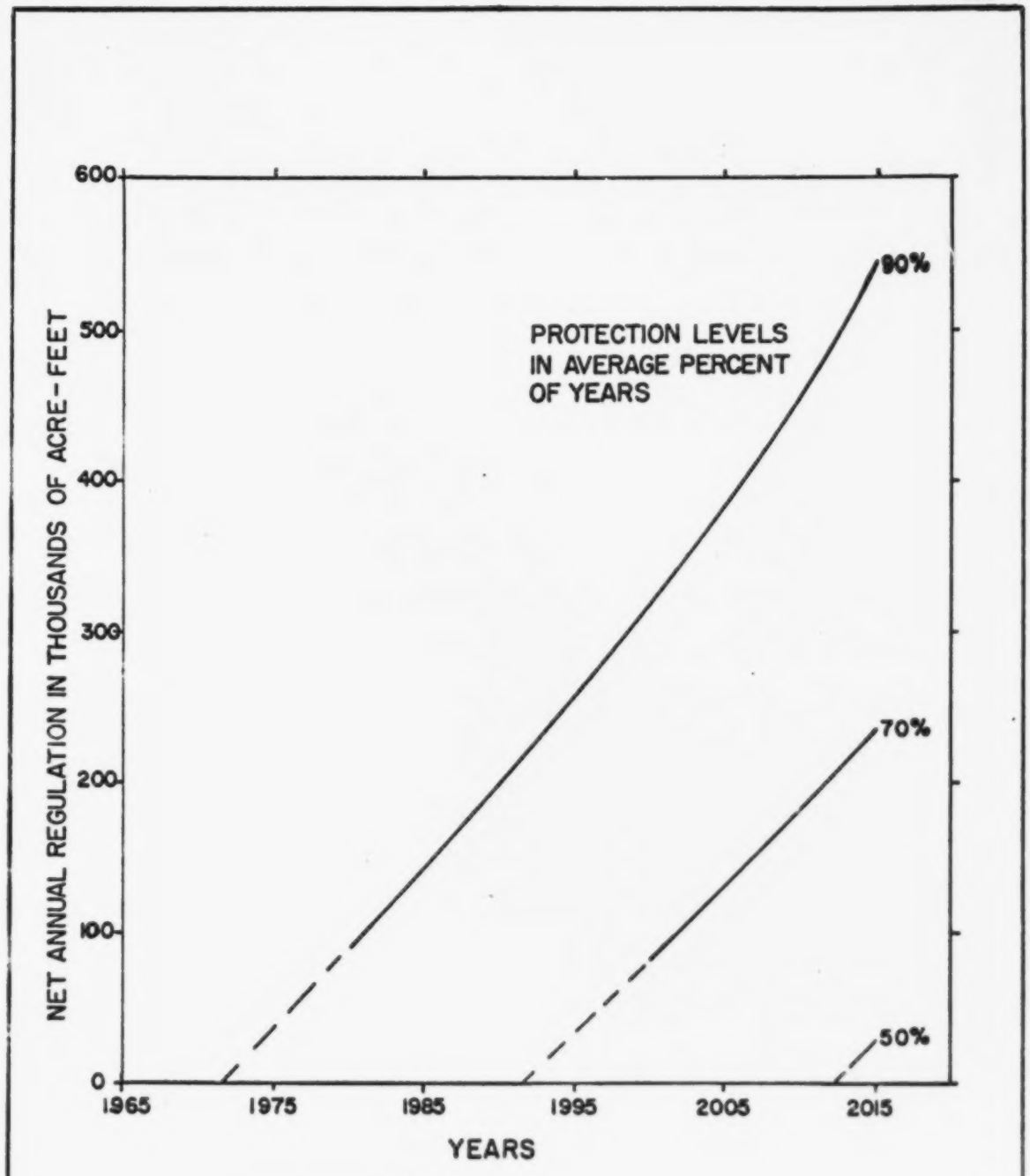
Mississippi River Headwaters Reservoirs Study

Protection Level (Percent)	Year of Development		
	1980	2000	2015
90	91	318	545
70	0	85	238
50	0	0	30

Figure VIII-1 shows this trend graphically. The flow regulation requirement for quality control in Table No. VIII-3 and Figure No. VIII-1 have been increased 20 percent to compensate for problems of synchronization of releases and needs and conveyance losses.

Alternatives

Several alternatives to storage in the headwaters reservoirs for quality control purposes on the Mississippi River in Subarea I were considered. The cost of a single purpose reservoir, with on-stream transmission to Subarea I, was determined from general cost data, [56] but the lack of a suitable site eliminated this plan. [57] Other reports [1,39] have discussed plans to bring water by pipeline from Lake Superior and the St. Croix River. A vertical lift from Lake Superior of about 520 feet and a pipeline length of more than 160 miles indicate that less costly alternatives exist. Four routes for diversion of water from the St. Croix River, through various natural lake systems, have been studie . [1] The use of gravity flow through and storage in the lakes would require obtaining easements on residential land around the lakes and along the route.



WATER RESOURCES STUDY

MISSISSIPPI RIVER HEADWATERS RESERVOIRS

TREND IN REGULATION REQUIREMENT

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VI KANSAS CITY, MISSOURI

Figure VIII-1

The static head and pipeline lengths necessary are shown in Table No. VIII-4.

Table No. VIII-4

Characteristic of Routes for Diversion of St. Croix River Water Mississippi River Headwaters Reservoirs Study

Routes	Static Head	Length of Pipeline
1	300 feet	10 miles
2	250 feet	9 miles
3	220 feet	6 miles
4	137 feet	11 miles

Enlarged connecting channels between some lakes would be necessary.

Since flow requirements for quality control are as great as seven and a quarter times waste flow, the diversion or controlled release of the treated wastes would be less costly.

The storage of waste during periods of low flow was investigated and economical feasibility was dependent upon location of area suitable for a holding pond without large transportation costs. The maximum size and cost of a holding pond in the Pig Eye Lake area was calculated. The present Minneapolis-St. Paul Sanitary District Plant is located in the Pig Eye Lake area. The long Meadow Lake area which is adjacent to the possible southwest regional plant [43/] was considered as a potential holding-pond site. Around the possible southeast or northwest regional plants [43/] potential holding-pond sites of similar size were not located. The economically potential storage capacity of the Long Meadow Lake area and the Pig Eye Lake area is insufficient to give a 90 percent protection level in 2015.

Pumpage of the waste flow which could not be assimilated by the Mississippi River was considered, but the alternative plan decided upon was a storage pond in Pig Eye Lake Area and pumpage of the waste. The storage pond delays the necessity for pipeline construction until 1995 by allowing controlled waste releases and permits construction of smaller pumping capacity by acting as an equalization pond.

IX. VALUE OF STORAGE

"The net contribution to public health, safety, economy, and effectiveness in use and enjoyment of water for all purposes which are subject to detriment or betterment by virtue of change in water quality, the net contribution may be evaluated in terms of avoidance of adverse effects which would accrue in the absence of water quality control, including such damages and restrictions as preclusion of economic activities, corrosion of fixed and floating plant, loss or downgrading of recreational opportunities, increased municipal and industrial water treatment costs, loss of industrial and agricultural production, impairment of health and welfare, damage to fish and wildlife, siltation, salinity intrusion, and degradation of the aesthetics of enjoyment of unpolluted surface waters, or, conversely, in terms of the advantageous effects of water quality control with respect to such items. Effects such as these may be composited roughly into tangible and intangible categories, and used to evaluate water quality control activities. In situations where no adequate means can be devised to evaluate directly the economic effects of water quality improvement, the cost of achieving the same results by the most likely alternative may be used as an approximation of value." 53/

The value of storage for quality control is based on the most likely alternative in the absence of a change in the operating plans to release the net regulation requirements from the headwaters reservoirs.

The alternative plan is a 24,000 acre-foot storage pond in the Pig Eye Lake area and three 65 mgd, 15 mile pipelines to the confluence of the St. Croix and Mississippi Rivers at Prescott, Wisconsin. Pumpage of the waste to Prescott was selected after studying three pipeline routes from Pig Eye Lake area. The routes considered are presented in Table No. IX-1.

Table No. IX-1

Mississippi River Headwaters Reservoirs Study

Destination	Pipeline Route	Distance (Miles)	Static Head (Feet)
St. Croix River at Afton	Parallel to State Highway 18	12	300
Mississippi River at Prescott	Parallel to CB&Q tracks	17	0
Mississippi River at Prescott	Parallel to U.S. Highway 61	15	170

The shorter route to the St. Croix River was eliminated because of the static head. The route paralleling the Chicago, Burlington, and Quincy tracks was eliminated on physical limitations. The route paralleling U. S. Highway 61 was chosen as the most favorable one. The greater flow of the combined rivers also favors the Prescott point of discharge.

The requirements and cost of the alternative plan selected is shown in Table No. IX-2.

Table No. IX-2

Requirements and Cost of Alternative Plan
Mississippi River Headwaters Reservoirs Study

Requirements Construction & Maintenance	Date of First Cost	Annual Cost*	1965 Annual Value***
Storage Pond	1972	$ 36,000	$ 29,000
1-65 mgd, 15 mile pipeline	1995	210,000**	86,000
DO	2002	210,000**	70,000
DO	2010	210,000**	55,000
Operation	1995	25,000**	10,000
			$250,000

*Capital cost amortized over 50 years at 3%
**Developed from cost data 24/ adjusted to ENR index of 950
***Discounted at 3%

The benefits are described in terms of avoidance of adverse effects which would accrue in the absence of water quality control. Treated waste from Subarea I discharged into the Mississippi River during low-flow conditions will cause deterioration of water quality so as to discourage or endanger, or preclude the existing and potential use for:

Public water supplies in the section of the river from the Minneapolis-St. Paul Sanitary District waste treatment plant to the St. Croix River junction.

Health of boaters and fishermen in the polluted conditions developing below the treatment plants outfalls.

Sport and commercial fishing as pollution contributed to the development of less desirable fish species, as well as the tainting of fish flesh.

Water Contact sports with discoloration, taste and odor caused by residual mineral and organic material.

Picnicking, camping, and aesthetic enjoyment due to odors, gasification, oil, sludge, and scum in the river.

The benefits with water quality control are that the above adverse conditions will be adverted.

The primary beneficiaries of the proposed water quality control program are the 1.5 million resident population of Subarea I and visitors who utilize the 24-mile reach of the Mississippi River for fishing, boating, skiing and other recreational purposes. The benefits attributable to water quality control in the Mississippi River will be substantially within Subarea I between the points of waste discharge in the subarea and the junction of the St. Croix River. The necessity for flow regulation for quality control arises from the waste produced in Subarea I. By virtue of the multiplicity of benefits (tangible and intangible) that are derived through maintenance of stream quality and the large number and varied nature of the people to whom these benefits accrue, the benefits attributable to measures specifically designed to achieve water quality control through streamflow regulation may be regarded as widespread and in harmony with the National goals for pollution control.

X. MAP OF AREA

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XII. EXHIBITS

Exhibit No. 1

Determination of Water Quality

Mississippi River Headwaters Reservoirs Study

The determination of water quality takes into consideration the wastes which will result from the economic development of an area and the effects of these wastes on stream regimen. At any point in a stream the water quality will be the result of mixing various qualities and quantities of water which make up the total flow modified by forces such as re-aeration and evaporation.

An estimate of waste loads likely to be discharged to the stream is the first step necessary in forecasting water quality conditions. Estimated waste loads are given in Table No. XII-1

Table No. XII-1

Estimated Waste Loads

Mississippi River Headwaters Reservoirs Study

Area Year	Return Flow (MGD)	Untreated Ultimate BOD (mg/l)
Grand Rapids		
1965	11	180
2015	25	178
Subarea I (Minneapolis-St.Paul)		
1965	200	267
1980	304	429
2000	441	406
2015	572	388

An ultimate BOD of 0.25 lbs./capita was used to determine municipal waste concentrations. Industrial waste concentrations were estimated from information obtained during field investigations. The return flows were estimated at 90 percent of the water requirements except for 1965 conditions in Subarea I where consideration was given to present miscellaneous water uses, which include the control of lake levels for aesthetic and recreational purposes having limited waste return flow.

The pollutional effect of waste loads on a receiving stream is a function of a number of variables. The main assumptions used in evaluating the need for quality control requirements are enumerated below:

1) Waste discharged to the streams of the basin will continue to be primarily organic in nature and specific mineral and/or organic toxicants will not be a significant problem.

2) Sufficient treatment will be provided to remove 90 percent of the Biochemical Oxygen Demand (BOD). A removal of 90 percent is as high as can be reasonably expected with any degree of certainty even with the best treatment now provided by conventional sewage treatment plants. 52/

3) Uniform mixing of wastes and receiving waters will occur.

4) Water for quality control is required to maintain the dissolved oxygen concentration of the mixed water in the stream at no less than 4.0 mg/l.

After determining the amount of concentrations and points of loading of the waste flows, the oxygen-sag method was used to determine the quality requirements for three different periods. The summer period was assumed to be three months long and to have an average water temperature of 25°C. The winter period was assumed to be three months and have an average water temperature of 1°C. The spring and fall periods were assumed to be six months long and to have an average water temperature of 10°C. For the free flowing reach of stream below Grand Rapids and for the navigation locked stream below Minneapolis-St. Paul f. "self purification" factors of 1.7 and 0.85 were used respectively for the critical summer period calculations.

Considering the needs for water and the cost of providing this water, a degree of protection of 90 percent, represented by a 10 percent probability of flows being equal to or less than those provided for, was used.

Exhibit No. 2

General Operating Data

Mississippi River Headwaters Reservoirs

Reservoir	Winnibigoshish	Leech	Pokegama	Sandy	Pine	Gull
Normal spring stage	8.0	0.5	6.0	7.0	11.0	5.0
Desirable summer range	10.0-10.5	1.8-2.2	8.75-9.25	8.75-9.25	12.75-13.25	6.0-6.25
Original operating limits	0' to 14.2'	0.5' to 5.24'	4.5' to 12'	0.6' to 11'	1.3' to 18.5'	1.0' to 7.0'
Capacity, original operating limits, ac-ft.	967,900	637,000	120,800	72,500	177,500	70,800
Present operating limits	6' to 14.2'	0' to 5.24'	6' to 12'	7' to 11'	10' to 18.5'	5.0' to 7.0'
Present ordinary operating limits	8' to 10.5'	0.5' to 3.0'	6' to 10'	7' to 11'	11' to 14'	5.0' to 7.0'
Capacity, present operating limits, ac-ft	166,000	305,000	60,000	38,000	40,000	26,000
Flowage rights acquired to stage of	18'+	9'+	16'+	15'+	22.5+	11.0+
Maximum stage ever attained	14.45'	5.18'	13.50'	17.51'	18.24'	7.3'
Number of times upper operating limit has been exceeded	2	0	18	18	0	8
Number times flowage limits have been exceeded	0	0	0	1	0	0
Maximum stage attained in 1950	14.23'	4.11'	12.97'	17.51'	15.09'	7.26'
Zero of gage						
(U.S.E. Datum)	1,290.08'	1,293.76'	1,265.27'	1,209.00'	1,218.20'	1,190.00'
(M.S.L., 1912 Adj.)	1,289.47	1,293.23	1,264.89	1,207.70	-	1,188.14
(M.S.L., 1929 Adj.)	1,288.94	-	1,264.42	1,207.31	1,216.32	1,187.75
Reservoir in operation	1884	1884	1884	1895	1886	1912
Watershed Area, Sq. Miles	1,442	1,1163	660	421	562	287

Exhibit No. 3

Municipal Water Supplies a/
(Over 1,000 Population)

Mississippi River Headwaters Reservoirs Study Area

Municipality	1960 Population	Source	Rated Plant Capacity (Million Gallons/day)	Average Plant Output (Million Gallons/day)
Athlo	1,829	2 wells	-	0.390
Albany	1,196	2 wells	-	0.060
Anoka	10,562	4 wells	4.530	0.750
Bayport	3,205	2 wells	1.310	0.200
Belle Plaine	1,931	3 wells	-	0.120
Bemidji	9,958	7 wells	0.340	0.300
Blaine	7,570	Wells	3.100	-
Bloomington	50,948	Minneapolis	-	-
Bovey	1,086	Well & Coleraine	0.790	0.110
Brainerd	12,898	5 wells	3.200	1.600
Brooklyn Center	24,336	4 wells	5.550	0.870
Brooklyn Park	10,197	Wells	2.880	-
Buffalo	2,322	2 wells	1.440	0.100
Burnsville Twp.	2,716	2 wells	0.936	-
Cambridge	2,728	2 wells	0.812	0.200
Cass Lake	1,586	3 wells	0.720	0.250
Chaska	2,501	3 wells	1.300	0.060
Circle Pines	2,789	Well	1.500	-
Cokato	1,356	2 wells	1.115	-
Cold Springs	1,760	2 wells	-	0.022
Coleraine	1,346	3 wells	2.380	0.165
Columbia Heights	17,593	Minneapolis	-	-
Coon Rapids	14,931	6 wells	5.600	-
Cottage Grove Twp.	4,850	2 wells	2.880	-
Crosby	2,829	3 wells	0.790	0.150
Crystal	24,283	1 well	0.720	-
Delano	1,612	3 wells	1.550	0.120
Eagan Twp.	3,382	3 wells	1.860	-
Edina	20,501	9 wells	10.200	1.800
Elk River	1,763	2 wells	0.210	0.110
Excelsior	2,020	Gideon Bay, Lake Minnetonka	1.230	0.300
Falcon Heights	5,927	St. Paul	-	-
Farmington	2,300	3 wells	2.590	0.100
Foley	1,112	2 wells	-	0.100
Forest Lake	2,367	2 wells	0.738	-
Fridley	15,173	2 wells	2.590	0.790
Glencoe	3,216	3 wells	0.900	0.065
Golden Valley	16,559	Minneapolis	-	-
Grand Rapids	7,265	3 wells	2.800	0.600
Hastings	8,965	4 wells	3.360	0.700
Hopkins	11,370	3 wells	0.180	1.665
Howard Lake	1,667	2 wells & Howard Lake	0.720	0.050
Hutchinson	6,267	3 wells	2.900	0.160
Inver Grove	5,753	2 wells	1.620	-
Jordan	1,479	3 wells	1.200	-
Kenyon	1,651	2 wells	9.000	0.160
Lauderdale	1,670	St. Paul	-	-
Litchfield	5,078	7 wells	-	0.175
Little Falls	7,551	6 wells	1.500	0.060
Long Prairie	2,434	3 wells	1.600	0.080
Mahtomedi	2,127	3 wells	2.020	-
Maple Lake	1,018	well	0.160	0.025
Maplewood	18,519	St. Paul	-	-
Medina	1,472	Well	0.216	-
Melrose	2,135	4 wells	1.120	0.300
Mendota Heights	5,028	St. Paul	-	-
Milaca	1,871	3 wells	0.760	-
Minneapolis	482,872	Mississippi River	180.000	50.700
Minnetonka	25,037	5 wells	2.632	-
Minneiska	2,211	1 well	0.144	-
Monticello	1,477	Well	0.576	-
Morningside	1,981	Minneapolis	-	-
Mound	5,440	3 wells	-	0.265
Moundsview	6,416	1 well	2.160	-
Nashwauk	1,717	Well	0.480	0.170
New Brighton	6,448	4 wells	3.870	0.033
New Hope	3,552	Well	1.440	0.200
North St. Paul	6,320	3 Wells	3.600	0.250
Oakdale Twp.	2,138	Well	1.150	-
Osseo	2,304	2 wells	1.650	0.100
Park Rapids	3,047	3 wells	1.350	0.220
Paynesville	1,736	Well	0.720	0.050
Plymouth	9,578	Well	0.360	-
Princeton	2,353	3 wells	-	-
Robbinsdale	16,381	5 wells	6.300	1.800
Rosemount	1,068	2 wells	0.303	0.016
Roseville	23,997	St. Paul	-	-
St. Anthony	5,084	3 wells	2.300	-
St. Cloud	33,815	Mississippi River	9.000	2.900
St. Joseph	1,487	Well	2.700	0.030
St. Louis Park	43,310	13 wells	14.500	4.500
St. Paul	313,411	Mississippi River & Lakes	84.000	42.600
St. Paul Park	3,267	3 wells	1.150	-
Sauk Center	3,573	2 wells	2.800	-
Sauk Rapids	4,038	2 wells	-	0.100
Savage	1,094	2 wells	0.510	-
Shakopee	5,201	3 wells	2.900	0.108
Shoreview	7,157	Well	0.720	-
South St. Paul	22,032	4 wells	8.350	1.250
Spring Lake Park	3,780	1 well	1.440	-
Staples	2,706	3 wells	1.120	0.100
Stillwater	8,310	4 wells	5.030	1.011
Waconia	2,048	2 wells	1.200	0.060
Wadena	4,381	5 wells	2.600	0.100
Waite Park	2,016	2 wells	0.960	0.040
Walker	1,180	2 wells	0.930	0.016
Watertown	1,044	2 wells	-	0.020
Wayzata	3,219	2 wells	2.880	0.465
West St. Paul	13,101	St. Paul	-	-
White Bear Lake	13,849	5 wells	2.590	-
Wilmar	10,417	3 wells	2.300	0.500
Winsted	1,383	3 wells	-	0.150
Woodbury Twp.	3,014	Well	0.720	-

Exhibit No. 4

Basic Data on Sources of Municipal Pollution 44/

Mississippi Headwaters Reservoirs Study Area

Receiving Stream Name of Municipality	Water Course Mileage	Population Served by Sewers	Municipal Population 1960	Waste Treatment Provided	Discharge Estimated MGD
Mississippi River					
Bemidji	1,311	8,960	9,958	Secondary	1.3
Cass Lake	1,275				
Cass Lake	-	1,430	1,587	Primary	0.07
Leech Lake River	1,223				
Walker	-	1,066	1,180	Secondary	0.07
Deer River					
Deer River	-	890	992	None	0.09e
Mississippi River					
Grand Rapids	1,180	6,540	7,265	None	0.65e
Trout Lake					
Coleraine and Bovey	-	1,210 980	1,344 1,086	Secondary Same Plant	0.18 0.25
Swan River	1,138				
Marble	-	790	879	Primary	0.08e
Nashwauk	-	1,540	1,712	None	0.15e
Calumet	-	720	799	Primary	0.07e
Keewatin	110	1,490	1,651	Secondary	0.15e
Mississippi River					
Aitkin	1,055	1,650	1,829	None	0.16e
Serpent Creek	1,029				
Crosby	-	2,370	2,629	Primary	0.24e
Pine River	1,023				
Pine River	-	700	775	Secondary	0.07e
Mississippi River					
Brainerd	1,003	12,089**	12,898	Secondary	1.5
Crow Wing River	990				
Park Rapids	-	2,720	3,047	Secondary	0.2
Menagha	85	720	799	Secondary	0.07e
Sebeka	65	740	823	Secondary	0.07e
Wadena	55	3,960	4,381	Secondary	0.39e
Verndale	-	550	608	Secondary	0.06e
Bertha	80	510	562	Secondary	0.05e
Eagle Bend	-	550	611	Secondary	0.06e
Staples	30	2,440	2,706	Secondary	0.02e
Alexandria	75	6,040	6,713	Secondary	0.37
Parkers Prairie	-	800	886	Secondary	0.08e
Long Prairie	60	2,170	2,414	Secondary	0.22e
Clarissa	80	510	569	Secondary	0.05e
Mississippi River					
Camp Ripley	982	-	-	Secondary	-
Little Falls	965	6,800	7,551	Secondary	0.68e
Sauk River	930				
Osakis	60	1,260	1,396	Secondary	0.13e
Sauk Centre	45	3,478**	3,573	Secondary	0.35e
Melrose	45	1,920	2,135	None	0.19e
Freeport	-	530	615	Primary	0.06e
Waite Park	10	1,810	2,016	Primary	0.18e
Mississippi River					
Sauk Rapids	929	3,630	4,038	St. Cloud	
St. Cloud	927	31,333**	33,815	Secondary	3.5
Clearwater River	914				
Watkins	-	670	744	Secondary	0.07e
Kimbol Prairie	20	480	535	Secondary	0.05e
Annandale	-	890	984	Secondary	0.09e
Mississippi River					
Monticello	900	1,330	1,477	Secondary	0.13e
Elk River	884	1,580	1,763	Secondary	0.16e
Crow River	879				
Paynesville	-	1,580	1,754	Secondary	0.16e
Atwater	100	810	899	None	0.08e
Litchfield	50	4,530	5,078	Secondary	0.46e
Dassel	-	780	863	Secondary	0.08e
Cokato	-	1,220	1,356	Secondary	0.12e
Howard Lake	-	910	1,007	Secondary	0.09e
Maple Lake	-	920	1,018	Secondary	0.09e
Buffalo	-	2,090	2,322	Secondary	0.21e
Wilmar	165	10,696**	10,417	Secondary	1.05e
Hutchinson	50	5,590	6,207	Secondary	0.56e
Hector	110	1,170	1,297	None	0.12e
Buffalo Lake	-	640	707	None	0.06e
Glencoe	60	2,890	3,211	Secondary	0.29e
Watertown	25	940	1,046	Primary	0.09e
Delano	-	1,450	1,612	Secondary	0.15e
St. Michael	-	640	707	Secondary	0.06e
Rum River	871				
Isle	155	480	529	Primary	0.05e
Onamia	90	380	845	Secondary	0.08e
Milaca	65	1,640	1,821	Secondary	0.18e
Princeton	50	2,120	2,353	Secondary	0.21e
Cambridge	40	4,343**	2,738	Secondary	0.43e
Mississippi River					
Anoka	871	9,510**	10,562	Secondary	0.95e
Coon Rapids Dam	866				
Minnehaha Creek	847				
Maple Plain	-	680	756	Secondary	0.07e
Wayzata	-	2,900	3,219	Secondary	0.29e
Minnesota River	845				
Bella Plaine	50	1,740	1,931	Secondary	0.17e
Jordan	30	1,330	1,479		0.13e
Shakopee	20	4,740**	5,201	Primary	0.47e
Mississippi River					
Minneapolis & St. Paul Sanitary District	836*	1,041,700		Primary	145.00
White Bear Lake		15,560	12,849	Secondary	1.56e
South St. Paul		19,830	22,032	Secondary	1.98e
Hastings		9,310	8,965	Primary	0.93e
St. Croix River	810				

e - Estimated at 100 gpcd
* - Mileage 836 is above Ohio River - 1,800 miles above mouth of Mississippi River
** - Includes State waste institutional

Exhibit No. 5

Generalized Geologic Section - Highland Park Area, St. Paul, Minnesota 5/

Mississippi River Headwaters Reservoirs Study

System	Formation and member	Thickness (ft)	Altitude (ft above msl)	Ground water
Pleistocene	Glacial drift	110	1,000	Small to moderate quantities of water available from sand and gravel lenses.
Ordovician	Decorah formation	90	890	Small quantities of water available from fractures, fissures and solution cavities.
	Platteville formation	40	800	
	and Glenwood member	10		
	St. Peter sandstone	150	750	(Water level of Mississippi River below Ford Dam) Small to moderate quantities of water available.
	Shakopee dolomite	40	600	
	New Richmond sandstone	10		
	Oneota dolomite	80	550	Large quantities of water available.
Cambrian	Jordan sandstone	90	470	
	St. Lawrence formation	50	380	
	Franconia formation	190	330	Small to moderate quantities of water available from sandstone beds.
	Reno & Mazomanie members			
	Tonah member			
	Birkmose member			
	Woodhill member			
	Dresbach formation	275	140	
	Galesville member			
	Eau Claire member			
	Mt. Simon member			
	Hinckley sandstone	220	-135	Moderate quantities of water available.
Precambrian	Red Clastic Series	More than 1,000	-355	

Limestone · Sandstone · Dolomite · Shale · Conglomerate

Exhibit No. 6

Historical Streamflows [45/]

Mississippi River Headwaters Reservoirs Study

Station	Drainage Area Sq.Miles	Location	River Mile	Years of Record	Flow in CFS Maximum	Minimum	Average
Mississippi River at Grand Rapids, Minn.	3,370	2.5 miles upstream from Prairie River	1,182.0	79	12,500	0	1,107
Mississippi River at Aitkin, Minn.	6,140	One mile downstream from Mud River	1,055.9	17	20,000	236	2,782
Mississippi River near Anoka	19,100	6½ miles downstream from Anoka, Minnesota	864.8	31	75,900	586	6,761
Mississippi River at At. Paul, Minn.	36,800	Six miles downstream from Minnesota River	839.3	64	125,000	636	9,836
Minnesota River near Carver, Minn.	16,200	2½ miles south of Carver, Minnesota	36	28	64,100	79	3,051
*St. Croix River at St. Croix Falls, Wis.	5,930	In St. Croix Falls, Wisconsin	52.2	60	54,900	75	4,043
Mississippi River at Prescott, Wis.	44,800	200 feet downstream from St. Croix River	811	34	155,00	1,380	14,790

*Flow regulated by power plant upstream